INFLUENCE OF DE-COHERENCE EFFECTS ON SONAR ARRAY GAIN: SCLAED EXPERIMENT, SIMULATIONS AND SIMPLIFIED THEORY COMPARISON

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Gaultier Real[a,b], Xavier Cristol[b], Dominique Habault[a], Jean-Pierre Sessarego[a], and Dominique Fattaccioli[c]

[a]: Laboratoire de Mécanique et d'Acoustique (LMA), CNRS, 31 Chemin Joseph Aiguier, 13402 Marseille cedex 20, France, mail : real@lma.cnrs-mrs.fr, habault@lma.cnrs-mrs.fr, sessarego@lma.cnrs-mrs.fr.

[b]: Thales Underwater Systems SAS, 525 route des Dolines, 06903 Sophia-Antipolis, France, mail : xavier.cristol@fr.thalesgroup.com.

[c]: DGA Naval Systems, avenue de la Tour Royale, BP 40915, 83050 Toulon Cedex, France, mail : dominique.fattaccioli@intradef.gouv.fr.

Abstract: *Our study focuses on the subject of acoustic wave propagation through spatially fluctuating ocean. The fluctuations are here linear internal waves (LIW) and we developed an experimental protocol in water tank in order to reproduce the effects of LIW on ultrasound propagation. The present paper gathers the results obtained in terms of coherence function (second-order moment) for various configurations. Typical regimes of the $\Lambda\Phi$ plane developed by Flatté were explored, resulting into coherence function becoming narrower as the saturation increases. We also relate the coherence function to an array gain degradation parameter, δAG, which accounts for how the system performance will be mitigated in a given configuration. δAG was calculated for various sizes of vertical linear array (VLA) and showed an important dependence on the VLA's length. Typically, in any case (scaled experiment, computer simulations and simplified theory), we note that the longer the VLA, the greater the corresponding δAG. Moreover, as the saturation induced by medium fluctuations increases, δAG increases as well. This highlights the need for corrective signal processing techniques when large VLAs are used in a fluctuating environment. Signal processing techniques from various domains (e.g. adaptive optics, radio) are also studied.*

Keywords: *coherence, array gain, tank experiment, acoustic fluctuations, internal waves.*

1. INTRODUCTION.

Since the early XVIIIth century, scientists studied the limitations of systems performance due to medium fluctuations [1]. The topic of wave propagation through randomly fluctuating media is addressed in many references [2,3]. The influence of these fluctuations on the system performance (detection, localization) is critical in acoustics (in air and underwater) [4-7]. A novel experimental protocol was proposed in [8] and detailed in a companion paper [9]: it allows to isolate the fluctuations due to LIW from other sources of signal de-coherence (scattering from the sea surface or the seabed) and provide reproducibility and control. Calculations of the second-order moment (or mutual coherence function, MCF) are proposed in this paper, using the experimental data acquired in our scaled experiment. A parameter accounting for the array gain degradation is deduced from the MCF [10]. These results are compared, with a satisfying agreement, with simulations [11,12], empirical calculations [6] and simplified theory [13].

2. EXPERIMENTAL PROTOCOL.

The experiments conducted here follow the scheme described in reference [9]. An ultrasonic signal (f=2.25MHz) is propagated through the RAFAL (manufactured as presented in reference [9]), and the measurement of the acoustic pressure field throughout specific regions of the three-dimensional space is conducted. A diagram of the experimental configuration is given in Fig.2:

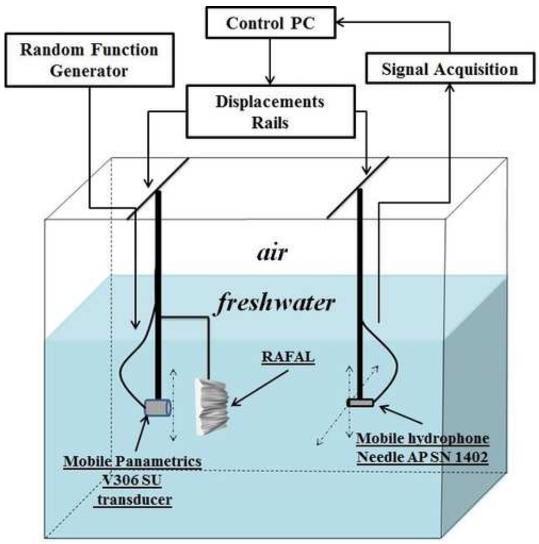

Fig.1: Experimental configuration diagram.

The configurations studied spanned from the unsaturated regime (US_i) to the fully saturated regime (FS_i) through the partially saturated regime (PS_i) defined in [14]. In this paper, the index i increases with increasing saturation.

3. COHERENCE FUNCTION

The mutual coherence function (MCF) is often used to evaluate the correlation of the acoustic wave received by a linear array. The interspectral matrix is first computed, then averaged across the iso-spaced sensors, leading to a function of the sensor spacing $\Gamma(l)$, such that [5,15]:

$$\Gamma(l)=\left|\left\langle\left\langle\frac{p(n)\,p^{*}(n+l)}{|p(n)||p(n+l)|}\right\rangle_{N}\right\rangle_{N_r}\right|. \tag{1}$$

Four calculations are proposed: the simplified theoretical results [13], the scaled experiments results, and simulations from PE codes (Propagation in 3D Tank Experiment configuration – P3DTEx, Propagation in 3D Corresponding Ocean Medium – P3DCOM). The results in terms of MCF are satisfying: in the fully saturated regime, the simulations match the scaled experiments results. The simplified theory provides a narrower coherence function, meaning that it overestimates the de-coherence. In the partial saturation case, similar conclusions can be drawn (though P3DCOM is close to the simplified theory case). Finally, the unsaturated case shows a good agreement between all calculations.

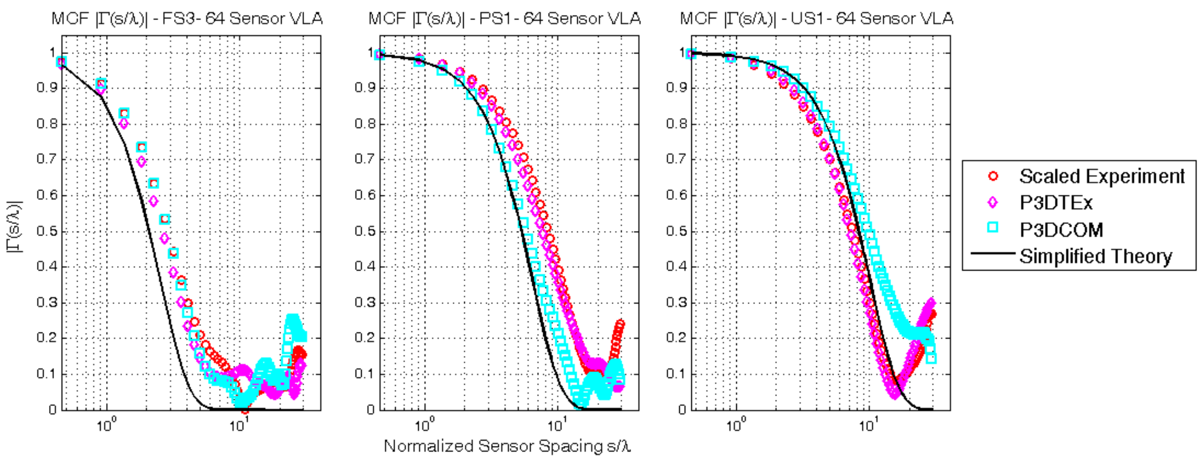

Fig.2: MCF $|\Gamma(s/\lambda)|$ calculated in full (left), partial saturation (middle) and unsaturation (right).

The evolution of the MCF is very consistent as a function of the saturation. In fact, a more saturated case leads to a narrower coherence function and, hence, to a more degraded array performance.

4. ARRAY GAIN DEGRADATION.

Following [10], the array gain degradation can be evaluated from the MCF:

$$\delta AG = G_{th} - 10\log\left(1 + \sum_{l=1}^{N} \frac{2(N-l)}{N}\Gamma(l)\right), \tag{2}$$

where $G_{th} = 10\log(N)$ is the theoretical array gain, and N is the number of sensors. The results obtained with this calculation are presented in Figure 3. They are compared with the same calculations as the MCF, and also to the results obtained by Fattaccioli et al. [6], given by:

$$\delta AG = \begin{cases} 10\log\left(\dfrac{L_a}{L_V/\lambda}\right) - 4 & \text{if } L_a > 5L_V/\lambda \\ 0.9\left(\dfrac{L_a}{L_V/\lambda}\right) - 0.6 & \text{if } L_V/\lambda \le L_a \le 5L_V/\lambda \\ \dfrac{1}{3}\left(\dfrac{L_a}{L_V/\lambda}\right)^{1.8} & \text{if } L_a < L_V/\lambda \end{cases}, \tag{3}$$

where L_a is the array length (expressed as a function of the normalized sensor spacing s/λ and L_V/λ is the normalized correlation length.

A very good agreement is found in the unsaturated regime for all array lengths in all cases. The simplified theory and empirical calculations are in very good agreement. Our scaled experiment results are consistent with the simulations carried out. Despite some differences between simplified theory, empirical calculations and our measurements and simulations in the other saturation regimes, the evolution of δAG is very consistent throughout the cases studied: the effect of increasing fluctuations is noticed on the AG degradation. We also notice the critical influence of the array length: as anticipated, the longer the VLA the more important the AG degradation (as predicted by the coherence function).

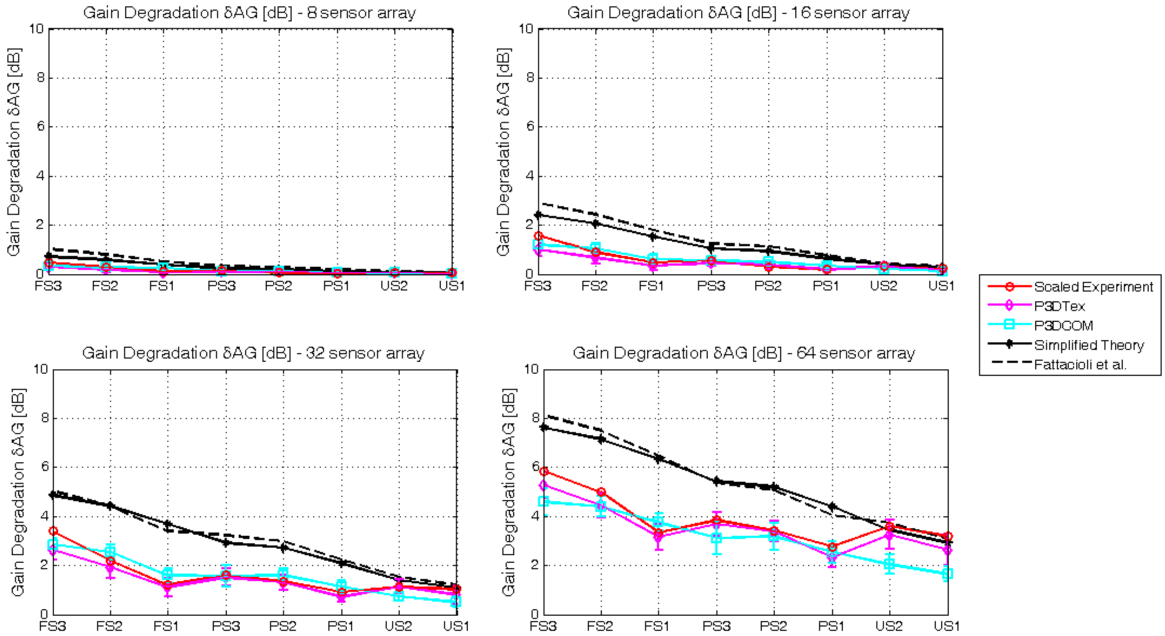

Fig.3: Array gain degradation δAG calculated in all saturation configurations for four VLA sizes (8, 16, 32 and 64 sensors).

5. CONCLUSION

In this paper, the array gain degradation due to environmental fluctuations was calculated using the mutual coherence function (or MCF). Theoretical and empirical results were compared to simulations and scaled experiments data, with satisfying agreement. The size of the linear array plays a decisive role in the sensitivity to the medium fluctuations. Indeed, in an unperturbed environment, a large array would perform better than a smaller one, but in our case, the degradation increases with the array size. In order to compensate for the observed degradations, corrective signal processing techniques should be used. Algorithms from other domains (optics, radio [16]) may be tested for underwater acoustic detection.

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